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THE SPECTRUM OF α^2 CANUM VENATICORUM, 5000–6700 Å*

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ABSTRACT

A complete list is given of all lines observed between 5000 and 6650 Å in the spectrum of α^2 CVn. Approximately three-quarters of the features have been identified. Lines of Pb II and P II are not present. Lines of Gd III and Pr III vary in equivalent width and radial velocity in a manner similar to the singly ionized rare earths. Lines of Cl II are present and also behave like those of a rare earth.

I. INTRODUCTION

The star α^2 CVn is the prototype of the class of peculiar A stars known as spectrum variables. The spectral lines periodically vary in intensity and in wavelength. The variations in radial velocity have been studied most completely by Struve and Swings (1943), while Burbidge and Burbidge (1954) have examined the variation of equivalent widths. The lines of different elements have been roughly divided into three groups by Belopolsky (1913*a*, *b*, 1927), depending upon their intensity variations: Those of groups A and B have their maximum strength at phases 0.0 and 0.5, respectively, while lines of group C are constant. Furthermore, the magnetic field (Babcock and Burd 1952) and the color (Provin 1953) vary with the same period of 5.47 days.

The principal source of line identifications for α^2 CVn is the monumental work of Struve and Swings (1942, hereinafter called S²). It contains approximately 3000 lines in the wavelength region 3080–4710 Å. Burbidge and Burbidge (1954, hereinafter called B²) measured the equivalent widths of many features on spectra spread throughout the period and performed a crude abundance analysis based on the line identifications of S².

The study of the spectrum of α^2 CVn in the yellow region is of great interest. In the blue and ultraviolet, misidentification can easily occur because the spectrum is unusually crowded, and the presence of elements not found in normal stars cannot easily be established because the number of random coincidences between stellar features and laboratory wavelengths is expected to be large. Furthermore, many elements of interest do not have strong lines in the blue region. In view of the great progress that has been made in the analysis of the spectra of the rare earths in the last ten years, it was thought desirable to investigate the spectrum of α^2 CVn in the region 5000–6700 Å.

II. OBSERVATIONS AND THE IDENTIFICATION PROCEDURE

Twenty spectra were taken with the 72-inch camera of the coudé spectrograph of the Hale telescope in the first half of 1965. These plates (IIaD and IIaF emulsions) have a dispersion of 6.7 Å mm^{-1}. The observational material is listed in Table 1, which also includes the phase and usable wavelength range of each plate. (The phases used here were computed with the formula established by Farnsworth 1932; no change in period was noticed.) The plates together cover the range from 4800 to 6800 Å. Intensity tracings of the spectra were made on the microphotometer of the Robinson Laboratory,

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using the wedges for calibration. It is possible that at a later date equivalent widths will be determined for some of the lines. The positions of the lines relative to the comparison spectrum of the iron arc were measured on an oscilloscope Grant machine for all the plates. In the case of blends, the central wavelength of the feature was measured.

The wavelengths of the stellar features as determined by their positions with respect to the comparison spectra we call the o wavelengths. The o wavelength of each feature was then corrected for the solar motion and for the average radial velocity, from the work of S², for lines of group A at the phase (ϕ) at which the plate was taken. This procedure yields the A wavelength of each stellar feature. Similarly, B and f wavelengths were calculated for each stellar feature using the appropriate radial velocities of Cr II and Fe II lines (see § VI).

TABLE 1

OBSERVATIONAL MATERIAL

Phase	Plate	Wavelength Range (Å)
23 04	Pb8700D	5000–6370
23.04	Pb8701D	5000–6380
*1.09	Pb8479aF	6160–6700
23.22	Pb8706D	5680–6480
1 27	Pb8493IID	6200–6700
1 27	Pb8493D	5600–6200
17 35	Pb8616D	5560–5840; 5920–6400
17.37	Pb8618F	5560–6700
17.37	Pb8619D	5560–6560
23 37	Pb8707D	5650–6500
22 49	Pb8676D	5000–6280
17.53	Pb8623F	5560–6700
17 53	Pb8624D	5400–6560
23 53	Pb8710D	5450–6470
23 59	Pb8713D	5560–6350
23 59	Pb8714F	5560–6750
22.64	Pb8679F	5450–6700
22.64	Pb8681D	5000–6200
22 64	Pb8684F	5400–6700
22.84	Pb8693D	5100–5900; 6000–6700

* Exposed 5 A.M. P.S.T. night of January 16–17, 1965.

Thus, each plate yields *four* different wavelengths for each line measured in that plate. Because the variations in radial velocity over the period differ from group to group, the wavelengths A, B, and f do not coincide, nor do they differ by a constant at all phases. For example, the Fe II line at 5197.59 Å is identified with a stellar feature whose A wavelengths at phases 0.09 and 0.49 are 5197.48 and 5197.62; the B wavelengths are 5197.68 and 5197.52, respectively, and the f wavelengths of the stellar feature are 5197.59 and 5197.56, respectively. We note that the best agreement between the stellar wavelengths at these two phases is obtained for the f wavelengths; hence we can conclude that the identification as an Fe II line is probably correct.

With the o wavelengths, atmospheric lines can be eliminated. We have used the *Solar Spectrum Tables* by Moore, Minnaert, and Houtgast (1966) as a source of wavelengths for atmospheric lines. In a few cases, where the line in the spectrum of α^2 CVn is obviously largely stellar, we have denoted the presence of an atmospheric line as a component in the blend.

Line identifications were assigned on the basis of the wavelengths A, B, and f of each feature. Tolerance between laboratory and stellar wavelengths was taken as ± 0.15 Å, except where the laboratory wavelengths were known to be inaccurate. A line was attributed to an ion of group A if the laboratory wavelength best matched the average over all plates of the A wavelength of the stellar feature. Assignments of lines to other groups were made in the same way. The variation in equivalent width of the feature over the period was also an aid in the identification. In ascribing lines to ions not previously recognized as present in α^2 CVn, it was required that all the lines of the ion behave in the same way with respect to variation in equivalent width and wavelength.

The basic lists used in the identification procedure were those of Moore (1959), Harrison (1939), and Meggers, Corliss, and Scribner (1961). The last reference is especially useful for the singly ionized rare earths. Many other lists have been consulted, and the most useful of these will be noted later.

It was impractical to use all of the plate material in obtaining the identifications. Three high-quality plates for each wavelength region were selected which were evenly distributed over the period, having phases near 0.0, 0.5, and 0.8 or 0.3. It was found by comparison with the remaining plates that very few features occur on a plate somewhere in the cycle that do not occur on one of the three plates selected as typical for that wavelength region; perhaps one such feature occurs every 50 Å. For each of the three selected plates, the A, B, f, and o wavelengths were computed for each observed feature. These, plus the tracings, were used to identify the stellar features.

III. DESCRIPTION OF THE FINAL LINE LIST

The final identifications, covering the wavelength region 5000–6650 Å, are given in Table 2. The first two columns give the stellar wavelengths A, B, or f, at phases near 0.0 and 0.5, respectively. The radial-velocity system for which the wavelength was derived is indicated by the letter following the wavelength. The plates used to obtain these wavelengths are listed at the top of each page. The wavelengths given are those of the velocity group corresponding to the identifications. Thus, for an Fe II line, wavelength f of the stellar feature at phases 0.0 and 0.5 is listed. For unidentified features, the wavelength A is listed if the feature clearly is enhanced in strength near phase 0.0. In all other cases, wavelength f is listed if the wavelengths f obtained for the same stellar feature at different phases agree better than the A or B wavelengths of the same feature. The same holds for unidentified features with wavelengths of other velocity groups. The letters "bl" following the wavelength indicate that the feature on the tracings is wide and obviously blended. The beginning and end of regions of unusual complexity, where it is possible that more lines exist in the stellar spectrum than have been measured, have been indicated by asterisks.

Columns (3) and (4) contain estimates of the intensity of the stellar features at phases near 0.0 and 0.5. The plates used to obtain these intensities are listed at the top of the columns. It is not always true that the spectra from which the wavelengths were calculated are the same as those from which the intensity estimates were derived, as the former were selected partially on the basis of maximum number of lines measured in the comparison spectrum, and the latter for the quality of the tracings. The intensities are on a scale from 0 to 9, where 0-intensity lines have a central residual intensity greater than or equal to 0.95, and lines with intensity 8 have a central residual intensity of about 0.50. Some care was taken to make the intensity scale uniform over a range of continuum intensities, but small variations in the scale have probably occurred over regions separated by more than 100 Å. The tracings from which the intensities were estimated have comparable continuum intensities, so that the relative intensities at phases 0.0 and 0.5 could be accurately obtained.

The last column contains the identifications. The ion and laboratory wavelength modulus 10 is given. A tabulation of only one digit after the decimal point means that

TABLE 2

LINE LIST FOR α^2 CVn

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8676	Identification
5000				
00.09Abl		1	0	SmII 0.05;(ErII 0.38;NdII 0.44)
01.79f	01.96f	1	3	FeII 2.0;FeI 1.87
04.23f	04.19f	2	2 r	FeII 4 2;FeI 4 03; DyII 4 26
	06.90fbl	2	3	CuII 6.78;FeI 5.72
07.49f	07.59fbl			FeI 7.29
08.95f	09 02f	1	1	FeII 9 0;ErII 8 97
10.07f	10.17fbl	2	2	FeII 0 0;FeII 0.2; TiII 0.20
	11.99fbl	0	0	FeI 2.16;FeI 2.07
12.90A		1	0	
13.54A		1	0	TiII 3.71;(TiII 3.38)
15.67f	15.77f	1	2	FeII 5.7;(HeI 5.68)
17.03A		1	0	
18.47f	18.42f	3	5 r	FeII 8.43;(NiI 8.29)
19.91A	19.88Abl	2	2	FeII 9.48;VII 9.86; GdII 9 36;(CaII 9.98)
	21 60f	0	1	FeI 1.60,1 68
22 61f	22.64fbl	2	3	FeII 2.87;TiII 2.82;CeII 2.87, FeI 2 24
24.57f	24.75fbl	0	1	
25.87f		0		
26 83f	26 84f	2	2	FeI 7 14
29.17A	29.15A	0	0	
30.65f	30.66f	1	2 r	FeII 0 74;ScII 1.02
	31 93f	0	0	FeI 1 90;(CeII 1.97)
32.69f	32.66f	1	2 r	FeII 2.79;(NiI 2 75);(YbII 2 58)
33.85A	34.12A	1	1	NdII 3.52;PrII 4.42;HfII 4 33; (TmII 4 24)
35.75f	35.70f	2	3 r	FeII 5.77;(NiI 5.37)
36.95f	36 74f	2	2 r	FeII 6 92
37.88A	37.85A	1	0	TiII 7.81;CeII 7.77;PrII 7.46
41.00	40.97f	5	5 r	SiII 1.03;FeI 0.90;(HfII 0 82)
42.49A	42.55Abl	0	0	(NiI 2 19;PbII 2.5)
45.20f	45 15f	1	2	FeII 5 2
47.62f	47.65f	0	1	FeII 7.7
48.61f	48.45f	0	1	FeI 8.45;(AI .8 81)
50.71f	50.67f	1	1	? + GdII 0 88
52 12B	62.12Bbl	0	0	(Cℓ 2.15)
56.12f	56.07f	6	6 r	SiII 5.98;(SiI 6.31)(GdIII 6
57.29A		1	0	(HfII 7.03)
59.35Abl		1	0	
60 19f	60 29f	1	2	FeII 0.4
61.69f	61.70f	2	3 r	FeII 1.79
63.93A	64 17Abl	0	0	NdII 3 73;SmII 4 24
65 20f	65.17fbl	1	3	FeII 5 02;FeI 5.20
67 92f	67.92f	1	2	FeII 7 9
68.73f		2		FeI 8 77;ScII 8 86
70 92f	70 83f	2	3 r	FeII 0 96;(GdI 1 03)
72 38A	72 44Abl	2	1	TiII 2.30:FeI 2 08
73 94f	73 89f	2	2	FeII 4 06;(FeI 3 78)
75 78f	75 77fbl	3	3 r	FeII 5.83;HfII 5 92;(CeII 5 3
78 30A		2	0	CℓII 8.25;(SmI 8 06)
	78 49fbl			FeI 9 00
80.10A		0	0	LaII 0.21
	80 56A	0	0	HfII 0 44;NiI 0 53
82.15f	82 21f	2	3	FeII 1.9;FeII 2 3;(NiI 2 35)
83.60A	83 59A	3	2	
85 11B	85 17B	1	1	
86 29f	86 31f	1	2	FeII 6 4
87 29f	87 31f	1	2 r	FeII 7 25;(YII 7 42)
87 94A		0	0	
89 49f	89 26f	2	3 r	FeII 9.28
90 89f	90 92f	0	1	FeI 0 79;CrII 1 14
91.70A	91 86A	2	0 r	GdIII 1 70
93 51f	93.59f	3	4	FeII 3.47, 3 6
	94 98f	1	2	
97 14f	97 17f	3	4	FeII 7 38;FeI 7 00;CrII 7.29
98.59f	98.72f	1	2	FeI 8 59;GdII 8 38
99.73A		1	0	? + CℓII 9 30
5100				
00.73f	00.69f	3	5	FeII 0 66, 0 8

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8676	Identification
5100				
02.37A	02.49Abl	2	1	NdII 2.39;SmII 3.09;CℓII 3.04; (+f)
04 33Abl		0	0	SmII 4.48;YbII 4.42
	05.14f	1	2	f + NdII 5.21; YbII 5 03
06 15f	06 13f	1	2	VII 6 23
07.44f	07.41f	1	2	FeI 7.65;LaII 7 54;GdII 7 41
*				
09.00A		1	r	GdII 8.91
	09.36fbl		1	
09 88A		0		
	10.58Bbl		1	CrII 0.43;HfII 0.61;FeI 0.41
*				
	12 24f	1	2	ZrII 2 28;(FeII 1 9)
13 14f	12 92f		2	FeII 3.0
15.10f	15 11f	0	1	? + NiI 5.40
16.96f	17 06f	1	2	FeII 7.1;CeII 7.17;SmII 6.70
17 87A		0	0	YbII 7.72
19 28A	19 29A	1	1	(YII 9.12)
20.44f		0	0	FeII 0 34
20.89A		0	0	(CuII 0 75)
21 93f	21.92f	0	1	f + FeI 1 65
23.27f	23 30f	1	2	MnII 3.32;YII 3.21
24 17f		0	0	FeII 4.05; (BiII 4 03)
25 09f	25 06f	0	1	FeI 5 13;ZrII 4 98
25.91f	26 04f	0	1	FeII 6.19; FeI 6 22
27 12A	26.99A	2	2	SmII 7 11 + f
	27 67f		2	FeII 7 87
	28.70A	1	1	HfII 8 53;YbII 8.55
29.05A	29 16A		1	TiII 9 14
30.22f	30.13fbl	1	2	
31.77f	31.78f	0	1	NiI 1.77;FeI 1.48;(GeII 1.7)
	32.61f	0	1	FeII 2 67
34 17f	34 07f	1	2	? + FeI 3 70
35 32f	35 27f	0	0	f + PrII 5 13
36 02A	36.19f	0	1	FeI 6.09; YbII 5 98
	37 12Bbl	0	0	CrII 7 09:FeII 6 79;FeI 7 39
37 53A		0	0	
39.43f	39 37f	1	2	FeI 9 47; FeI 9 26

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8676	Identification
	40.40fbl	0	0	
40 93A		1	0	GdII 0 84
	41.34f	0	0	FeII 1 4
42 15A		2		YbII 2.28; (SeII 2 14)
	42 38f		1	FeI 2 54; (YbII 2 28)
44 26f	44 27f	2	3	FeII 4 4; FeII
45 61f	45 81f	2	3	FeII 5 9;FeII
47 54f	47 51f	1	1	
49 31f	49 26f	3	5	FeII 9 5 + ?
50 47f	50.49f	1	2	
51 75A	51.73A	1	0	VII 1 87
*	52.80f bl		1	
53 42B		2	2 r	CrII 3 49
54 48f	54 33f	2	2	FeII 4 4;TiII
57 33f *	57 37fbl	1	1	FeII 7 4;VII 7 LaII 7 43
58.08A		0	0	YbII 7 92:(CuI 8 09;AℓII 8.19
61 08f	60.91f	1	2	FeII 0.82;FeII 1 18;GdII 0 90
	63 30f bl		2	
63 95f		0		FeII 3 7
64 81A		0	0	NdII 5 14; FeII 4 69
66.48A	66.50A	1	0	
67 63f	67 58fbl	1	2	FeI 7 49
69 04f	69 03f	3	4 r	FeII 9.03; (FeII 9 73)
70 74f	70 69f bl	2	2	? + VII 1 13
71 51f	71.30f			FeI 1 61 + ?
73 07f	73 08f	2	2	FeII 3 00; YbII 3 11
*	75 08f	0	0	
76 03f	bl			FeII 5 9;GdII 6 30;CrII 6 24
77 49f	77 40f bl	1	2	FeII 7 5;FeI 7 MnII 7 65
78 79f	78 58f bl	0	1	FeII 8.7;GdII 8 84;(GeII 8 6
*	79.38f			FeII 8.95
	80 40f	0	1 r	FeII 0.53; (YbII 0 36)
	81 89f	0	1	FeII 1 97; SiII 1 90
83 46A	bl	2	1	LaII 3 42
83 59A	83 70A			TiII 3.72;(YbI 4.15)(PrII 3 8
85 70f	85 61f	3	3	SiII 5 54, 5 2 TiII 5 90

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8676	Identification
5100				
	86.77f	0	1	FeII 6 8
87 31A		1		GdII 7 24; CeII 7.45
88 63A	88.83A	1	1	TiII 8 70; (CaI 8.84)
89.94f	90.01f	0	1	
90 41A	bl	0	1	SmII 0 45
	90.78f			
91.51f	91.59fbl	1	1	FeII 1 58;CrII 1 46;ZrII 1.60; (VII 1 59;NdII 1 45)
92 91f	92 76f	2	2	SiII 2.86;FeI 2 35;NdII 2 62
	93 96f	0	1	
95 07A	95 10A			PrII 5.11; (PrII 5 31)
97 59f	97 56f	2	3 r	FeII 7 57
99.25f	99 15f	2	3	f + FeI 8 84
5200				
00.57A	00 83f	2	2	FeII 0 8, 1.0; YbII 0.54;YII 0.42;GdII 0 55; (SII 1 00)
02 46f	02 48f	1	2 r	SiII 2 41 (FeI 2 27)
03 88f	03 76f	3	3	FeII 3 7; LaII 4 15
05 65A	05 72A	3	2	YII 5 73;(CeII 5 52;YbII 5 57)
06 58A	06 61A	2	1	PrII 6 56
08 56B	08 41B	2	2	FeI 8 60; CrI 8 56
09 31f	09 31f	1	2	(BiII 9 29)
10.51A	10 61B	2	2	CrII 0 87; GdII 0 49
	12 58f		0	SII 2 61
13 85f	14 02f	1	2	FeII 4 0
15 74f	15 65fbl	2	3	VII 5 88;FeI 5 18;NdII 5 65
16 74f	16 85f	2	3 r	FeII 17 0
17 97A		3	0	CℓII 7.93; (YbII 7 94)
	18 78f	1	2	FeII 9 0; PrII 9 05
19 96A	19 99A	2	2	PrII 0 11
21 31A	21 39A	2	1	CℓII 1 34
22 40f	22 37f	1	1	
23 22f	23 26f	2	2	
	23 98	2	1	
25 23A	25 28A	2	2	(NdII 5 05)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
26 30A	26 25Abl	3	2	LaII 6.21;CeII 6 36;TiII 6 54
27 52f	27 42f	3	4	FeII 7 5
28 80f	28 78f	2	2	
	29 99f		0	FeI 9 86; (YbII 9.96)
	31 07f		1	
32 78A	32.72B	2	3	CrII 2.50;CeII 2.91;(FeI 2 95
34 44f	34 51f	3	4 r	FeII 4.62; (NdII 4.20)
35 60A		2	1 r	CeII 5.77
	37 34B	0	3 r	CrII 7 34
37 96f	37 97f	2	3	FeII 38 0
39 85f	39 88f	2	3	ScII 9.82:NdII 9 79;(CeII 9 8
41 13B	41 11B	2	2	VII 1 19
43 17f	43 20fbl	1	1	CrII 3 50;FeI 3 78;FeI 2 50
45 27f	45 29f	1	1	
46 74B	46 70B	0	0 r	CrII 6 75
48 02f	47 94f	1	2 r	FeII 8 03
49 55B	49 37B	1	1	CrII 9 40; NdII 9.59
51 26f	51 26f	1	2	FeII 1 3
	51.93A	0	2	MnII 1 82; PrII 1 74
53 64f	53 62f	2	1	(FeI 3.48) (PII 3 55)
54 80f	54 85f	1	1	FeII 4 92
57 08f	57 03f	1	2 r	FeII 6 89,7 2
58 23A	58 18Abl	0	1	(DyII 8 39;CeI 8 40;SmII 7 91
60 14f	60 22f	2	4	FeII 0.3
	61 60f		0	(CaI 1 71)
62 11f	62 26f	1	0	FeII 2 26;TiII 2 15;(TbII 2.1
	64 27f		3	FeII 2 2
64 55f		3		FeII bl; PrIII 4.44
	64 73f		3	FeII 4 80
	66 31fbl		0	FeI 6 56
68 47A	68 53A	1	0	TiII 8 62
70 06f	70 13fbl	1	1	(CaI 0 27); NdII 9 78
71 13A	71 11A	1	1	VII 1 26
72 36f	72 37f	2	3 r	FeII 2 41
75 06B	74 99B	2	2 r	CrII 4.99; (CeII 4 24)
75 94f	75 98f	2	4 r	FeII 5 99

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
5200				
78 12f	78 08fbl	0	0	FeII 8 27; †
79 95B	79 93B	1	2	CrII 9 92; CrII 0 08
81 34A		0		YbII 1 21
84 20f	84 43f	2	3 r	FeII 4.09; PrIII 4 70
86 77f	86 71f	1	1	
88 80B	88 77Bbl	1	1	(FeI 8 53)
90 02A	90 15Abl	1	1	YII 9 82;HfII 9 98;LaII 0 84
91 59f	91 57f	2	2	FeII 9 7
92 18A		2	0	PrII 2 10
*94 06A	94 13A	3	1	MnII 4 21; †
95 55A	95 73Abl	2	0	MnII 5 29(+?)
97 05A	97 17B	2	0	MnII 6 97 (CrI 7 36)
	98 83f	0	1	FeI 8 79
99 88A	99.95Abl	2	2 r	PrIII 9.99; MnII 9 28;HfII 9 85 (+f)
*				
5300				
	01 17A	0	0	(YbII 0 95)
02 37A	02 53Abl	2	2	MnII 2.32;LaII 2 62;NdII 2 29
	03 47f	0	1	FeII 3 42; (VII 3 26)
05 86B	06 08B	2	3	CrII 5 85; FeII 6 2
08 42B	08 35B	1	2 r	CrII 8 44
10 70B	10 67B	1	2 r	CrII 0 70
11 80A		0	0	ZrII 1.78;HfII 1 60;NdII 1 46
	13 61B	0	2	CrII 3.59; (TiII 3 76)
16 64f	16 58f	3	5	FeII 6 61; FeII 6 78
18 20f	18 13fbl	2	2	FeII 8.27;CrII 8 41;(ScII 8 35)
18 74A		1	0	
19 87A	20 13A	1	2	NdII 9 82(+f); YbII 1 14
22.04f	21 99f	1	1	FeI 2 05
22.95A		0	0	PrII 2 78
25 46f	25.45f	1	2 r	FeII 5 56
26.63A	26 71A	0	0	
29.46B	29 09Bbl	0	1	CrI 9 15; (OI 9 59)
30.72f	30.66f	2	1	CeII 0.58; OI 0.66
33.31A	bl	0	0	LaII 3.42;ErII 3.36;YbII 1 54
35.04B	34.83B	0	1	CrII 4 88; YbII 5 15

λ Pb8701	λ Pb8676	Int Pb8701	Int Pb8710	Identification
36 75B		0	0	TiII 6 79
37 79B	37 70Bbl	2	3	CrII 7 76; FeII 7 72
39 84f	39 72fbl	3	4	FeII 9 9;FeI 9 94;(XeII 9 3 (PrIII 0 15)
*42 35A	42 66A	1	0	SmIII 2 76 (+B
43 99A		2		PrII 3 86; ErII 3 93
	44 23f		1	
45 42A		2		YbII 5 66
	46 06Bbl	2	4	CrII 6 12
46 93B	46 97Bbl			CrII 6 54;FeII 6 49;(YbII 7 2 (+f)
47 67A		2	1	CeII 7 80; (GdIII 7 95)
*	50 37B		0	ZrII 0.36; VII 0 47
51 94f	51.87fbl	0	0	
53 48f	53 37fbl	2	1	FeI 3 39;CeII 3 53;YbII 2 96
55 34A	55 41A	2	1	
	57 17A	0	0	ScII 7 20;(NdI 6 91)(YbII 7 0
59 06B	59 01B	1	2	(YbII 8 66)
	60 54f	0	1	(GaII 60 6)
	61 81f	0	0	(FeI 1 64)
62 80f	62 87f	2	4 r	FeII 2 86
	63 86A	1	1	FeII 3 8
66 18B	66 15Bbl	2	2	f + GdIII 5 96
69 30B		0	0 r	Cr II 9 25
70 20f	70 26f	1	2	(FeI 9 97)
72 16A		1	1	GdII 2 21; NdII 1 94
73 01A		1		(TmII 3 01)
73 88f	74 00f	0	1	(FeI 3 71)
75 95f	75 90f	0	2	FeII 5 7
77 72f	77 78f	0	0	MnI 7 63
	79.14f	0	0	TiII 9 19
	81 19Abl	0	0	TiII 1 02;PrII 1 26;LaII 0 99
82.07A		1	0	LaII 1 92
	82 35f	0	1 r	FeII 2 52
83 31f	83 38f	1	2	FeI 3 37
84 15A		0		(NdII 3 85)
85 61Abl		1	0	DyII 5 65; NdII 5 90
87 02f	87 06f	1	3 r	FeII 7 13

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
5300				
	88 05f	0	1	
90 47f	9054f	1	2	
92.02A		1		CℓII 2 12
93 51A	93 65B	2	2	CrII 2.95;CeII 3 39;GdII 3 66; YbII 3 37
95.96f	95 86fbl	3	3	FeII 5 9;YbII 5 73;ErII 5 87
97 96	97 99f	2	3	
5400				
00 90A		1	0	MgII 1 05
02 21f	02 04f	2	4 r	FeII 2 11
04.00f		0	1	FeI 3 82; FeI 4 14
04.98f		0		
	05 21f		3	
05 64f		0		SiII 5.34; FeI 5 78
07 79B	07 72B	0	2 r	CrII 7 62
09.05f	09 03B	0	2	FeII 8 84; CrII 9 28
10 14B		0	1 r	CrII 0 39
	11 40A	1	1	PrII 1 56
12.70A		1	0 r	GdII 2.62
14 07f	14.01f	1	2 r	FeII 4 09
14 87f	14 97f	1	2	(FeI 5 21)
17 80A	17.94A	0	0 r	CeII 7 84
19.01A	19 04A	1	0	CrII 9 36;TiII 8 80;(XeII 9 15)
	20 00A	0	0	GdII 9 88
20 99B	20 85B	0	2 r	CrII 0 90
23 27A		2	0	CℓII 3.25; (SmIII 3.14)
	24 11f	0	1	FeI 4 08
25 03f	25 21f	2	2	FeII 5 27;CrII 5 29;(HgII 5 25)
26 51A		2	0	YbII 6 87; DyII 6 71
27 72f	27.75f	1	2 r	FeII 7 83
	28.70f	0	0	SII 8 64
29 86f	29 89f	3	4	FeII 0 1
32.78f	32 78fbl	2	3	FeII 2.98;FeI 2 95;SII 2.77; YbII 2.71
34 52f		0	0	FeI 4 53; (HoII 4.39)
36 70f	36 68f	0	0	(OI 6.83); (FeI 6.59)
38 02A		1	1	
	38 45A	0	r	SiII 8 62
39 72A	39 86A	0	1	SmIII 9.81

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
42 49f	42 43f	2	2	FeII 2.5;NdII 2 74;(AI 2.22)
43 41A	43 48A	2	1	CℓII 3.42; (DyII 3 35)(+f
44 25A	44 40f	2	2	CℓII 4 25 +f
45 91f	45 78f	1	2	FeII 5 91
46 85fbl	46 88f	0	1	FeI 6.92; (TiI 6 64)
47 59A		0	0	LaII 7 59
50 18A	50 15A	1	1	
51 10A	51 39A	0	0	NdII 1 12; FeII 1 60
54 14B	54 14B	1	1	TiII 4.05; (ErII 4 27)
55 82A	55 91B	2	2	CrII 5.80;NdII 5.82;(FeI 5 61 (SiII 6 45)
57.39A		2		CℓII 7 47; CℓII 7 02
	57.76f		2	
	59.19A	0	0	CeII 9 21
60.30A		2	0	SmIII 9 93;0 5
62.22f	62 13f	1	2	
	66.14f			FeII 6 0; SiII 6 43
66 42f		4	5	
	66.67f			FeII 6 9; SiII 6 87
69.42A	69.44B	1	1 r	SiII 9 26; DyII 9 11
71 39A		2	0	(YbII 1 17)
72 22A		2	r	CeII 2 30
	72 84fbl		1	FeI 2.72; CrII 2 63
	73 62fbl	1	1	FeI 3.91; TiII 3.52
75 86f	75 80f	1	2	
78 29B	78 25Bbl	2	3 r	CrII 8 35;SmII 8 29;FeII 7 67
79 49f	49 53f	1	2	
80.90A	81 17f	1	2	FeI 0.87;FeI 1 LaII 0.73;YII 0 76;(UII 1 22
82 31f	82 32f	1	3	FeII 2 4
83 76f	83.81f	1	1	(LiII 3 55)
87.66f	87 58f	1	3	f + FeI 7 75
88 82B	88 69B	1	1 r	CrII 8.97
90.68A		0	0	TiII 0 65
92 27f	92 26f	2	3	
93 69f	93 80f	1	2	FeII 3.9; SmII 3 72
	95 50f	1	1	(AI 5.87)

TABLE 2 (CONT'D)

	λ Pb8701	Pb8676	Int. Pb8701	Pb8710	Identification
	5400				
	97 44A		1	1	FeI 7 52; YII 7.42
	98 61f	98 56f	1	1	(FeII 8 2)
	5500				
53)	01 03A	01 09A	0	0	MnII 1 12
	03 13B	03 24Bbl	3	4	CrII 3 18;FeII 3 4;CrII 2 05
	06 21f	06.15f	4	3 r	FeII 6.27; (AI 6 11)
		06 98f	1	1	
	08 60B	08 56B	1	2 r	CrII 8.60; (NdII 8 40)
	10 95B	10 83B	2	4 r	CrII 0 68
	12.43A		1	0	(TiI 2 53)
	15 45A		1	0	DyII 5 40; HoII 5 56
	18 46A		1	0 r	CeII 8 49
	21 29A		1	0	
		21 60A	0	0	YII 1.70
	22 67A		0	0	(SeII 2 42)
	24 96f	25 20f	1	1 r	FeII 5 14; †
		27 87A	0	0	SmIII 7 85
	29 03f	29 04f	0	2	FeI 8 89; FeI 9 15
		30 10f	1	2	FeII 9 94;VII 0 10;YbII 9.95
	30.89A		1	0	(GdIII 1 14)
	32 10f	32 15f	1	2	LaII 2 17 + f
	32.88A		0	0	
	34 76f	34 81f	2	4 r	FeII 4 86
	36 25A		1	0	
	37 26A	37 50A	2	0	SmII 7 07; GdII 8 32
	39 16A		0	0	NdII 9.26;(TmII 0.03);(FeI 9.28)
		40 79f	0	1	SiII 4 74
	44.52f	44 50fbl	3	3	FeII 4.76,CrII 3 86;YII 4 61
	45 87A	45 93A	1	0	YII 6.02; NdII 5.91
		48 31A	1	1	NdII 8 47
	48.95f	48 99fbl	2	3	
	50 43A		1	1	
	53.33A		1	0 r	GdIII 3.30
	54 87f	54 93f	1	1	FeI 4 90
	56 13A		1	0	SII 6 01; (TbII 6 30)
		58 19f	0	1	FeI 7 95
	59.29A	59.64f	2	1	MnII 9.05 + f
7	61 21A	61.45A	2	2	CeII 1 46 + ?
		64 81f	0	1	SII 4 94

λ Pb8701	Pb8676	Int. Pb8701	Pb8710	Identification
66 85A		1	0	LaII 6.94
68 18f	67 96f	1	2 r	FeII 7 82
70 41A	70 41A	2	1	MnII 0 51
72 69f		0	0	FeI 2 87;(AI 2 55);(YbII 2
	73 62f	0	1	
74 84A		0	0	
76 31f	76 28f	1	1	FeI 6.10; SiII 6 66
78 02f	77 99f	2	2	MnII 8 15
79 67A	79 74A } 80 27f	1	1	(SmIII 9.88)
81 68f	81 72f	1	2	f + NdII 1 60
83 60A	83 75Abl	1	1	GdII 3 68; †
86 86f	86 97f	2	2	FeI 6 76
88 08f	88 21f	2	3	FeII 7 9; (GdIII 7 88)
91 40f	91 28f	2	1	FeII 1 38
92 47A		1	0	
	94 65f	0	0	FeI 4.67; NdII 4 43
94 98f		1	0	
	97 38f	0	0	(AI 7.46)
	98 25f	0	0	FeI 8.30
	99 53f	0	0	
5600				
01 05A		1	0	SmII 0 86; (CaI 1.29)
03 06f		1	0	FeI 2.96; (SmIII 3.23)
06 24f	06 33f	2	1	SII 6.11
08 86A		2	0 r	GdIII 8 95
	13 31f	0	0	AℓII 3 19
	14 41f	0	0	NdII 4 30
15 37f	bl	0	1	FeI 5 30; FeI 5 66
16 62A		0	0	SII 6 11
20 72B	20 70B	1	1	CrII 0 63
23 14A		2	0	PrII 3.05; (SeII 3.13)
	24 33f	0	1	FeI 4.55; PrII 4 43
27 44f	27 55f	0	1 r	FeII 7 49
28 31A		0	0	HoII 8 24
29.75A		0	0	
33.49A		2	1	
	37.12A	0	0	SmII 7.30
39 51f	39 60f	2	2 r	SiII 9 49
42 33A	42 55A	1	0	SmIII 2.26,2.4
43.92f	43 88f	2	1	

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
5600				
45 42f	45 43f	0	1	SII 5.62; (SiI 5 67)
47 19A		2	0	(SmIII 7 23)
48 82f	48 87f	1	2	
49 97f		0	0	FeI 0 01
51 62f	51 65f	2	2	f + YbII 1 99
53.36A		2	0	YbII 3 24
55 21f	55 29fbl	2	2	FeI 5 18; FeI 5 50
56 52f	56 67f	0	0	(NeI 6 66)
58 91A	58 95f	3	1	FeI 8.83; GdIII 8.98;HfII 8 83;(AI 9 13)
60 43f	60 34f	1	2 r	SiII 0.65; SII 9.95
61 34A		0	0	SmIII 1 32
63 11A		0	0	YII 2 95
65 26A		1	0 r	GdIII 5 22; (ErII 5 44)
67 66A		0	0	SmIII 7 54
68 53A	68 80A	1	1	NdII 8 87; CeII 8 94(+?)
69 47f	69 56f	1	1 r	SiII 9 59; PrII 9 55
71 40A		0	0	LaII 1 55
72 77Abl		2	0	
75 26B	75 26B	1	0	
77 11A	77 22A	2	1	PrII 7.04; (HgII 7 17)
	78 49B	1	2	CrII 8 42
	84 54f	1	0	
87 11A	87 31A	1	0	PrII 7 19
88 77f	88 80f	1	2	SiII 8 81; NdII 8 53
89 96A		1	0	
90 98f	91 04f	0	1 r	FeII 1 38
92 03A		0	0	TiII 1 99
	94 33f	0	0	
96 34A		0	0	(TmII 6 44)
97 78A		0	0	
5700				
00 43A		0	0	
01 35f	01 33f	1	1	SiII 1 37; CrII 1 46
03 11A	03 50Abl	0	0	LaII 3 32; SmII 3 46
06 53A	06 45A	1	1	SiII 6 37
	07 37f	0	0	(SmIII 7 46)
08 98A	08 88A	0	0	
13 60A		1	0	YbII 3 73
19 69A	20 00Abl	3	1	SmIII 9 72; GdIII 9 83
	21 09B	0	0 r	CrII 1 02
24 63A		1	0 r	GdIII 4 66
26 42A	26 46A	2	1	
30 24A	30 33Abl	2	1	YbII 0 02 + ?
31 52A		0	0	
33 04f	32 87f	0	0	FeII 2 72
33 87A	33 67A	1	0 r	GdII 3 86
37 74f	37 79f	2	2 r	FeII 7 68; SmII 8 01
39 35A		0	0	(AI 9 52)
41.83A		0	0	NdII 2 08
46 45A	46 50A	1	1	YbII 6 36
48 10B	48 20B	0	1	(NdII 8 15)
49 35A		1	0 r	GdII 9 41
51 48f	51.49f	0	0	
55 43f	55 54f	0	0	atm?
58 65A		0	0	
	59 27f	0	0	
63 04f	63 08f	1	1	FeI 2 99
65 33A	65 39A	0	0 r	PrIII 5 27
66 91A	66 93Abl	0	0	YbII 7 20; HfII 7 18,(+A)
68 88A	68 80Abl	1	0	CeII 8 90;LaII 9 07;LaII 9 34 PrII 9 15
71 05A		0	0 r	GdII 1 20
	74 05f	0	0	FeII 3 8
76 84A	76 84A	0	0	
80 20f	80 20f	3	4	FeII *
83 64f	83 71f	1	2	
84 63f	84 43f	1	2	FeII *
86 89A		2	0 r	GdIII 6.96; SmII 6 98
91 02Abl		2	1	PrII 1.38; (HgI 0.65; FeI 1 01;CrI 1 04)
	95 85f	0	1 r	FeII 5 87
96 72A		1	0	
98 64B	98 68B	0	0	
5800				
00 45f	00 57fbl	1	2 r	SiII 0 47; FeII 0 02
02 68A	02 71f	2	2	
03 88A		1	0	NdII 4 02; †
05 13f		0	0	FeII 4 9

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8676	Int. Pb8701	Int. Pb8710	Identification
5800				
06 88A	06 88A	2	2	SiII 6.74; (GdII 7 05)
11 79f	11 69f	2	2	FeII 1 93; NdII 1 57
13 66f	13 73f	1	2 r	FeII 3.67; (PrII 3 59)
20 90A		0	0 r	GdII 0 99
23 45f	23 31f	0	1	FeII 3 2; NdII 3 37
24 07A		0	0	(PrII 3 72); (YbII 4 33)
26 42f	26 53fbl	0	1	FeII 6 12;CrII 7 24;(MnII 6 29)
28 08f	27 91f	0	1	SiII 7 80
	29 36f	0	0	
30 49f	30 41f	1	2	
31 69A	31 61A	1	0 r	SmII 1 74
32 83A		0	0	
	33 96f	0	0	FeII 4 06
35 50f	35 58f	0	0	FeII 5 43;FeII 5 50;FeII 5 61
	38 94f	0	1	
42 21f	42 29f	1	2	f + NdII 2 39
44 75A	44 55Abl	3	1	PrII 4.41;PrII 5 06;GdII 5 71; DyII 5 65
	46 11f		1	SiII 6 13
47 23A		0	0	PrII 7 13
51 52f	51 57f	1	1	
52 38A		0	0	(NeI 2 49)
54 45f	54 33f	2	3	FeII 4 1; ScII 4 32
	58 01f	0	0	NiI 7 76 +?
58 34A		2	0	(CeII 8 56)
59 27A		0	0	
61 13A		1	0	TiII 0 92
62 04A		1	0 r	GdIII 2 09
66 38A		1	0	SmIII 6 44
67 42f	67 64f	1	1	SiII 7 50
68 33f	68 51f	2	2 r	SiII 8 40
71 74A	71 86A	1	1	GdII 1 81
	72 83A	0	0	EuII 2 98
74 15A		0	0	LaII 4 00
77 00		0	0	GdII 7 26;atm
82 03A		1	0	atm;(NeI 1 90)
85 67f		2	2	FeII*;atm
5900				
02 58A	02 97A	1	3	(FeII*?)
03 21A		2		PrII 3 13; SmII 3 50
13 93B	13 90B	1	1	CrII 3 87; GdII 3 52
15 18f	15 24f	1	1	SiII 5 27
20 57A		0	0	YbII 0 39;atm
22 20f	22 20f	2	1	? + atm
26 34A	26 40A	2	1	SmIII 6 45
28 85A		1	0	VII 8 86;atm
30 73f	bl	1	1	? + atm
37 52A	37 57A	1	0	(ErII 7 20)
38 87A		1	0 r	SmII 8 90
52 52f	52 57f	1	1 r	FeII 2 55 + at
54 39A	54 38A	1	0	? + atm
55 98f	55 83f	4	4	FeII*;PrIII 6 05;SmII 5 82
57 59f	57 62f	4	4 r	SiII 7 56
61 80f	61 78f	2	3	FeII*
64 47A	64 58A	2	1	? + atm
66 09A	65 74Abl	1	1 r	EuII 6 07;atm; SmII 5 7;(+f)
78 92f	78 94f	3	4 r	SiII 8 93;(GdI 8 93;(MnII 8 5
81 44A		0	0	PrII 1 21 + at
83 80f	83 92f	1	1	FeI 3.70; LuII 3 90
84 82f		1	0	FeI 4 80;atm

TABLE 2 (CONT'D)

λ Pb8701	λ Pb8623	Int. Pb8701	Int. Pb8684	Identification
5900				
87.66A	87.91Abl	3	2	GdII 7.85;YbII 7.91;GdII 7 11
88.78A		1	0	
90.56f		0	2	FeII 0 59
91.52A	9155A	2		FeII 1 38; YbII 1 51
94.17A		1	0	
94.78A		1	0	SmII 4 64
96.95A		1	0	CeII 7 05 + atm
99.03A	99.01A	1	0	PrIII 8 94; FeII*
6000				
01.41f	01.34f	0	1	
02.26A		0	0	atm + YbII 2 52
12.57A	12.94Abl	2	0	A + YbII 2 51
14 57A	14.77A	2	1 r	GdII 4.77; (CI 4 84)
15 56A	15 78A	2	1	ErII 5 76
18 27A		0	0	atm?
19.89A	19 85Abl	1	0	GdIII 9 85 +?
21.99A		1	0	YbII 1.92; (SmII 1 75)
23.66A		1	1	SmII 3.68; (YbII 4 08)
	23.92f			FeI 4 07
24.67A		0	0	
29 21Abl		1	0	VII 8.98;ZrII 8 64;(NeI 9 99) + atm
31.94Abl		2	0	GdIII 1.70; HfII 1 96
	32.28f	0	0	(AI 32 13)
36.29A		1	0	(XeII 6 20)
40 23A		1	1	
	40 48A			
40 73A		1		YbII 0 77
45 78f	45 67f	1	2	FeII 5 50(+A)
49.63A	49.66A	1	1 r	EuII 9.51; (GdII 9 50)
51 15A		1	0	(XeII 1 15)
52 99A		3	2	PrIII 3 01;YbII 2 88
	53 24Bbl			CrII 3 48
55 97A		2	0	(SeII 5.96); FeI 5 99
58 03A	58 13A	2	1	GdIII 8 10(+A)
58 87A		1	0	(BiII 8 96)
60 85f	61.05f	1	2	FeII 1 04; SmII 0 73
65 63A		1	0 r	GdIII 5.67
68 56A		0	0	YbII 8.64; (AℓII 8 46)
70 06B	69 71B	1	2	CrII 9 69; CrII 0 08
71 38f	71 43fbl	1	2	
73 64A		0	0	
75 19A		0	0	GdIII 5.14; YbII 5 21
76 92A		0	0	
81 78B	81 63B	0	1	CrII 1.51; (PbII 1 5)
	83 00f	0	1	
84 28f	84 16f	0	1 r	FeII 4 11
85 71A		0	0	
	86 04f	0	1	
87 99A		1	0	(PrII 7 82)
89 97A`	89 90Bbl	3	3	CrII 9.69; PrIII 0 02
92 87A		2	0	A + GdIII 2 50
	94 14fbl	0	0	FeI 3 66; FeI 4 41
99 76A	99 23Abl	3	2	
6100				
	02 43f	0	0	
03.41f		1	1	FeII 3 54
	12 08B	0	0	(CrII 2 26)
13 44f	13 45f	0	1 r	FeII 3 33
18 34A		1	0	
	20 98A	0	0	VII 0 98
22 38A	22 48A	1	0	MnII 2.44; (MnII 2 80)
24 20A		1	0 r	GdIII 4 21
	24 84A	1	1	SmII 4 88; (SiI 5 03)
	28 31A	0	0	YbII 8 18; (SII 8 21)
29 01A		1	1	MnII 9 02
	29 31B			CrII 9 23
30 81A		1	0	MnII 0 79
32 20		0	0	? + MnII 1 92
	34 86A	0	0	(GdIII 4.62; HfII 5 10)
	39 45Bbl	1	0	? + CrII 8 77
	40 96f	0	0	FeII 1 01
45.02A	45 18A	2	1	(SiI 5.08; GdIII 5 07)
47 69f	47 71f	2	2 r	FeII 7.74; (CrII 7 17)
49.13f	49 20f	1	2	FeII 9 24;SmII 9 10
	50 58f	0	1	

TABLE 2 (CONT'D)

λ Pb8479	λ Pb8623	Int. Pb8701	Int. Pb8684	Identification
6100				
52 44A	52.76A	1	0	YbII 2.57; GdIII 2 46
53 26A		1	0	GdIII 3 33
56 82Abl		1	1	OI 6 78; SmII 6 90
58 11A	58 19A	2	2	OI 8 19; (NdII 7 83)
60 21A	60 36A	1	1	PrIII 0 24;FeII 0 75;(LuII 9 94)
61 04A	61 21A	1	1	PrIII 1.22; PrII 1 19
64 48A		0	0 r	SmII 4 51
66 15A	66 19A	2	1	PrII 5 95
67 25A		0	0	
68 33A		0	0 r	SmII 8 33
72 49A	72 69A	1	0	(LaII 2 73)
73 14A		0	0 r	EuII 3 05
75 08f	75 12f	2	2	FeII 5 16; SmII 4 96
75 61A		0	0	YbII 5 58
77 28B		0	0	(CrII 6 95) (+A)
78 39A		0	0	
79.45f	79 23f	1	2	FeII 9 38; CrII 9 17
81 18A		0	0 r	SmII 1 05
82 01A		1	1	(AℓII2 28)+f
82 81A		0	0 r	SmII 2 89
83 87A		0	0	NdII 3 91
85 26f		0	0	FeII 5 34
86 31A	86 27A	1	1	
87 39A		0	0	(GdIII 7 24)
88 88A	88 56Abl	2	0	A + YbII 9 03
91 16A		0	0	(YbII 0 81)
93 80A		0	0	
95 50A	95 65A	2	2	PrIII 5 63; (CrII 5 18)
97 01A		0	0	
97 88A		0	0	
98.85A		1	0 r	GdIII 8 85
	99 65A	0	1	LuII 9.66; (FeII 9 16)
6200				
00.12A		0	0	SmII 0 08
01 19A		0	0	
03 08A		0	0	(HfII 2 85)
04 71A		0	0	
06 00A		0	0	
	07 99B	0	0	CrII 8 18; YbII 8 11

λ Pb8479	λ Pb8623	Int Pb8701	Int Pb8684	Identification
08 44A		0	0	
10 93A		0	0	(NdII 0 68)
12 96A		0	0	GdIII 2 79
13 87A	13 42Abl	2	1	
15 21A		0	0	YbII 5 56
16 05A		0	0	GdIII 6 04
16 65A		0	0	
17 78f		0	0	(FeII 7 95)
18 26A		0	0	
18 91A		0	0	
19 66A		0	0	
20 93A		2	0 r	GdII 0 86
23 04A	22 76A	1	0	HfII 2 81
23 58A		0	0	YbII 3 65
24 77f	24 74f	0	0	
26 73B	26 44B	0	1	CrII 6 66;VII 6 29;(AℓII 6 1
27 15A		0	0	
27 98A	28 19A	0	0	GdII 7 96; LuII 8 14
29 27A		0	0	YbII 9 36
30 76f		0	0	FeI 0 73
31 09A		0	0	
31 69f	31 71f	0	0	(AℓII 1 78); (SmII 1 70)
33 69f	33 54f	1	2	FeII 3 52; YbII 3 38
34 40A		1	0	SmII 4 20
35 47A		0	0	LuII 5 36
36 62A		0	0	
37 54f	37 32f	0	2	f + SmII 7 66
38 43f	38 40f	2	3	FeII 8 43; (GdIII 8 48)
39 70f	39 73f	3	5	FeII 9.95;CrII 9 77;(SiII 9 6
	41 34f	0	1	
42 84A	42 51Abl	1	1	GdIII 2.39;LuI 2 34;(GdIII 2
	43 56f	0	0	(AℓII 3 36)
44 12A	44 53Abl	1	0	SmII 4.21; (PrII 4 34)
	45 54A	1	0	ScII 5 63
46 27A		1	0	
47 45f	47 45f	2	4	FeII 7 56
48 75f	48 88f	1	2	FeII 8.75; (HfII 8 95)
49 59A		0	0	
	50 83f	0	0	

TABLE 2 (CONT'D)

Pb8479	Pb8623	Pb8701	Pb8684	Identification
6200				
51 53A		0	0	
52 20A		0	0	
	53 68f	0	1	(FeI 3 82)
	54 67A	0	0	
55 92A		0	0	
56 37A		0	0	
	56 83A	0	0	SmII 6 66
58 32A	58 44A	0	0	(GdIII 8 63)
59 61A		0	0	
60 54A		1	0	GdII 0 31; YbII 0 79
61 61f	61 69f	0	0	(OI 1 55)
63 23A	63 39A	0	0	NdII 3 23
64 31A		0	0	
65 69A		0	0	
67 07A		0	0	SmII 7 28
69 89A		0	0	YbII 9 95
	71 17A	0	0	YbII 1 16; HfII 1 05
71 87A		1	0	CeII 2 05; CrII 1 83
73 81A	73 87A	0	0	LaII 3 76
6300				
00 96A		1	0	ScII 0 70; SmII 1 12
05 23f	05 45f			atm + FeII 5 31; CrII 5 60
12 43B	bl	0	0	? + SII 2 68
13 71A		1	1	ZrII 3 57
15 33A	15 20Abl	1	1	FeI 5.31; SmII 5 78
17 88f	17 91f	3	3	(CaI 8 11); (XeI 8 06)
19 11A	19 59Abl	1	1	atm + NdII 9 69
24 04A		2	1	? + YbII 4 43
27 21A	27 31A	1	0	SmII 7 47
28 61f	28 58f	1	1	f + SmII 8 85
32 02f	31.90f	2	2 r	FeII 1 95
34 06A	34 19A	1	1	(GaII 4 2)
39 88A		0	0	SmII 0 06
44 19A		1	1	CeII 3 96
47 18f	47 09f	6	6 r	SiII 7 10; (GdIII 7 08)
49 06A		1	0	
51 05f	50 97f	0	1	
52 40A	bl	1	0	
57 09f	57 14f	1	2	
	62 72A	1	1	

Pb8479	Pb8623	Pb8693	Pb8684	Identification
69 25f	69 42f	1	2 r	FeII 9 45
71 45f	71 38f	5	5 r	SiII 1 36; (GdIII 1 35)
74 41A	bl	0	0	OI 4 31;LaII 4 08;YbII 4 81
75 69f	75 81f	2	3	FeII 5 96
77 46A		0	0	
81 11A	81 17A	0	0	GdII 0 96
82 27A	82 36A	0	0	GdII 2 18
83 67f	83 73f	2	2 r	FeII 3 75
85 29f	85 44f	1	1	FeII 5 46; NdII 5 20
86 67f	86 84f	1	1	FeII 6 75
6400				
00 26A		1	0	GdIII 0.19; (FeI 0 01)
02 81A		0	0	YbII 2 64
	05 26A	0	0	
10 05A		0	0	(SmII 0 34)
11 12f	11 21f	0	0	(CuII 1 18)
13 34A		1		
13 99A	14 16A	1	3	PrII 3 70
15 67B		1	r	CrII 5 59
16 92f	16 98f	2	3 r	FeII 6 91
18 46A		0	0	
19 09B	18 98B	0	1 r	CrII 8 87
23 07A	22 94A	1	1	(SeII 2 90)
25 72f	25 73f	0	2	
26 81A		1	0	SmII 6 64
29 29A		1	0	PrIII 9 26
32 72f	32 74f	2	2 r	FeII 2.65; (YbII 2 73)
33 74f	33 84f	1	1	FeII 3 85
34 79A		0	0	
35 48A		1	0	
37 59A		1	0 r	EuII 7 64
38 17A		0	0	
41 06A		0	0	(YbII 0 79); (TbII 1 03)
41 73A		0	0	(CuII 1 70)
42 96f	42 93f	2	3 r	FeII 2.97; (LaII 3 05)
44 81A		1	1	PrIII 4.74; GdII 4 84
46 74f	46 45f	0	1	FeII 6.43; (MnII 6 28)
47 43A		0	0	
51.17A	51 11A	1	0	

TABLE 2 (CONT'D)

λ Pb8479	λ Pb8623	Int Pb8693	Int Pb8684	Identification
6400				
53 46A		0	0	YbII 3.30;(OI 3 64);(SnII 3 50)
55 09A		1	0	HfII 5.85
56 34f	56 34f	3	3 r	FeII 6.38; (OI 6 01)
65 67A		1	1	
82 27f	82 21f	2	2	FeII 2 21 + atm
91 37f	91 63fbl	1	1	FeII 1 28; TiII 1 61 + atm
6500				
00 14A	00 13A	0	0	PrIII 0 04
04 08A	04 07A	0	0	
06 50f	06 49f	1	2	FeII 6 33; (NeI 6 53)
24 80f	24 72f	0	0	
31 24A	31 28A	0	0	(YbII 1 26)
40 30f	40 31f	1	1	HfII 0 01
50 50A	50 67Abl	2	1	
62 95f	62 79f	9	9	Hα 2 82
66 59A		0	0	PrII 6 75 + atm
67 41A		0	0	HfII 7 39
76 04A		0	0	
77 25A		0	0	GdIII 7 07
80 06A		0	0	
81 15A		0	0	NdII 0 94
92 43A	92 41A	0	0	(YbII 2.69); (NiI 2 47)
99 98f	99.96f	1	2	f + HfII 9 76
6600				
21 90f	21.90f	2	2	
27 16f	27 33f	2	2	FeII 7 28
36 59A	36 68A	0	0	LaII 6 53
43 04f	43 07f	0	0	
45 15A		1	0	EuII 5 11
60 51f	60 56f	1	1	SiII 0 52
71 93f	71 86f	1	1 r	SiII 1 88; (GdIII 1 85)
77 31f	77 35f	1	1 r	FeII 7 33

the laboratory wavelengths were felt to be inaccurate. Such cases (as well as the symbol "Fe II*") are discussed individually later. In the case of blends the most important contributor is listed first, but for rare-earth blends this is often difficult to determine. If an important contributor cannot be identified, we indicate it by "+?". In some cases it is possible to deduce the velocity group of the unknown contributor, which is then indicated by "+A," "+B," or "+f." Identifications given in parentheses are considered less reliable because of the following: (1) the other contributors can account for all of the observed blend, though this contributor should be present; (2) there is an insufficient number of strong lines in the spectrum of the ion to verify that it is actually present; (3) the wavelength disagrees with that of the stellar feature by more than 0.15 Å, but the lines should be present; (4) the stellar line seems too strong to be due to this ion.

We note that in the region past 6200 Å there are many unidentified lines of 0 intensity which on the tracings can barely be distinguished from the noise, and which resemble atmospheric lines. Furthermore, these features appear to be at different wavelengths from plate to plate. However, no atmospheric lines are listed at the appropriate wavelengths by Moore *et al.* (1966). We have included these features until 6300 Å; in the region beyond 6300 Å, 0-intensity lines which look like atmospheric lines rather than stellar features on the tracings have not been included in Table 2. It is probable that a large number of the 0-intensity features between 6200 and 6300 Å are atmospheric lines.

Lines which were judged sufficiently unblended to be used in determining radial velocities are indicated by "r" immediately following the intensity estimates. Table 2 includes nearly 900 lines, approximately three-quarters of which have been identified.

IV. COMMENTS ON INDIVIDUAL ELEMENTS

a) *Oxygen*

The lines at λλ6156 and 6158 of O I are present, and are not noticeably weakened compared with normal B stars. However, these lines are blended with λ6156.9 of Sm II and λ6157.8 of Nd II. If a crude attempt is made to remove these blends by subtracting the equivalent widths of nearby features of Sm II and Nd II whose laboratory intensities are comparable with those of the rare-earth lines near λ6158, the resulting strength of the O I lines is consistent with the strength of the infrared triplet observed by Sargent and Searle (1962).

b) *Neon*

No lines can definitely be attributed to Ne I; λ6402 is absent. However, using the reddening-free parameter Q, where $Q = (U - B) - 0.72(B - V)$, as an indication of the effective temperature, Sargent, Greenstein, and Sargent (1968) have shown that α^2 CVn is sufficiently cool for this neon line not to be expected to be present.

c) *Phosphorus*

Five strong lines of P II were measured by B^2, based on the identifications of S^2. The equivalent widths of these lines (two of which at some phase have equivalent widths of at least 40 mÅ) correlate very poorly with the intensities given by Martin (1959). According to his list, multiplet 5 of P II (near 6040 Å) and three other lines near 6500 Å are stronger than the five lines that were measured by B^2 in the blue. The uniformity of this intensity scale has been verified by comparing the laboratory intensities with unpublished equivalent widths for κ Cnc kindly supplied by Sargent and Jugaku (1968).

Of the eight strong lines of P II expected in the red, there are only two coincidences, and one of the stellar features has a satisfactory alternative identification. We therefore conclude that there is no evidence for the presence of P II in the spectrum of α^2 CVn. Since P II lines appear very weakly in the spectrum of γ Peg (Aller and Jugaku 1958), it is possible that the abundance of phosphorus in α^2 CVn is normal.

d) *Chlorine*

Lines of Cl II are present in the spectrum of α^2 CVn. The strong lines of multiplets 2 and 3 are all present, and their intensities correlate well with the laboratory intensities. The multiplets of higher excitation potential are also present, but appear somewhat weaker.

Although Bidelman (1966) has suggested that the wavelengths given by Murakawa (1931) are more accurate than those of Kiess and de Bruin (1939), we have used the latter, as their list contains more lines and their intensity scale appears more accurate. In nearly all cases the difference between the two wavelengths is less than 0.1 Å.

The lines of Cl II behave like those of Eu II, which is rather surprising since the atomic number of chlorine is only 17. The variation in intensity of the lines between phase 0.0 and phase 0.5 is large; the lines are quite pronounced (with W_λ up to about 70 mÅ) at rare-earth maximum, and nearly disappear at phase 0.5. The form of the radial-velocity curve, allowing for the poor accuracy of the wavelengths, resembles that of the rare earths. This implies that neither the mass nor the charge-to-mass ratio of the most abundant ion of an element suffices to determine the velocity group to which an ion will belong.

The synthesis of excess chlorine could normally be correlated with excesses of phosphorus and sulfur. Special modifications of the α-process and the light-element *s*-process are required to understand excess Cl and Si, if nucleosynthesis is, in fact, involved.

e) *Iron*

Many of the strong lines of Fe I are present in α^2 CVn. However, in the region past 5000 Å, the Fe I lines are weak compared with the Fe II lines, so that it is difficult to ascertain the variation in radial velocity and strength of the neutral lines. It appears that lines of neutral and singly ionized iron behave in a similar manner over the period. Fe III is not present. Multiplet 5, which has strong lines of low excitation potential, is absent.

The *Multiplet Table* of Moore (1959) is incomplete with regard to the Fe II spectrum in the red. Additional Fe II lines have been found by checking to see whether the strong unclassified lines of Fe III given in the *Multiplet Table* are present in the lists of Glad (1956). A large fraction of the lines designated by Moore as unclassified Fe III are absent from Glad's extensive list, and since these show up strongly in the spectrum of α^2 CVn (as well as in Kohl's [1964] line list for Sirius), we assume they are in reality Fe II lines. Furthermore, the list of Dobbie (1938) furnishes many other Fe II lines absent from the *Multiplet Table*. About 90 per cent of Dobbie's list is present in the spectrum of α^2 CVn. The list of King (1938) has also proved helpful, especially those "lines which are wide and diffuse in the spark spectrum. . . . Their structure is denoted by 'N' . . . after the intensity number and in some cases only very rough wavelength measures could be made" (King, p. 111). We have found that the "N" lines, very few of which are classified, are quite strong in the spectrum of α^2 CVn, when a wavelength error of up to 0.5 Å is allowed. These lines are also present as unidentified in Kohl's (1964) work on the spectrum of Sirius. Since the stellar lines are very strong, their intensities vary as iron lines, and so many of the "N" lines are present, we have assumed that these also are Fe II lines, and have denoted them by "Fe II*" in Table 2, as no accurate wavelengths are available. It is probable that these lines represent transitions between levels with excitation potentials of 8 eV or greater.

It is of great importance that a reexamination and classification of the laboratory spectrum of Fe II be undertaken. Until then, most of the above identifications of Fe II must be regarded as less than certain, but very probable.

f) *Doubly Ionized Rare Earths*

We were fortunate to be able to obtain unpublished line lists for Ho III and Gd III from Dr. H. M. Crosswhite, and analyses of Yb III, Pr III, and Ce III have recently appeared (Bryant 1961; Sugar 1961, 1965, respectively). Of these ions, only Pr III and Gd III have strong lines in the wavelength region covered on our plates. Both are definitely present. It is difficult to judge the variation in phase of the few stellar Pr III features, since all of the six strong observed lines are blended, five with either Cr II or Fe II lines. The presence of an important contributor which varies like the rare earths is required to explain why these stellar features are not greatly weakened at phase 0.0 compared with phase 0.5.

More features have been attributed to Gd III, and for this ion the lines are definitely strongest at phase 0.0. We thus confirm the observation of Swings (1944) that the intensity variations are in phase for the singly and doubly ionized rare earths. Quantitative measurements of the lines of Gd III and Pr III will be made in the near future.

No analysis is available for Gd III. The lines of Pr III which are observed in α^2 CVn have excitation potentials less than 5 eV.

Note added in proof.—We recently received from Dr. Crosswhite a line list for Sm III, which is probably present in α^2 CVn. In cases where there was not sufficient room to insert the appropriate entry in Table 2, we have indicated the presence of Sm III as a component in a blend by the symbol "†". No analysis is available for this ion.

g) *Mercury*

Osawa (1964) has classified α^2 CVn as an "Si-Hg-Cr-Eu" star based on spectra with a dispersion of 60 Å mm^{-1} and using the appearance of the line at λ3984 as an indication of the presence of mercury. This line has an intensity ranging from 2 to 7 in S^2, so that it is clearly a strong line. According to Bidelman (1966), the first multiplet of Hg I has been seen in two stars showing the λ3984 line of Hg II.

There is one line of Hg II (λ6149) in the red whose laboratory intensity is equal to that of λ3984, and two lines (λλ5677, 5425) with slightly smaller intensities. No stellar features can be definitely associated with these three Hg II lines. It is possible that the absence of these red lines is due to their high excitation potential. Until transition probabilities for the strongest Hg II lines can be measured, such an explanation must be regarded as tenable.

There is a strong Hg I line at λ5460.7. The nearest stellar feature, at λ_A5460.3, cannot be attributed to Hg I because of the discrepancy in wavelengths.

The presence of mercury in the spectrum of α^2 CVn is therefore uncertain, since a line of intensity 6 is observed at λ3984 (according to S^2), which corresponds roughly to an equivalent width of 100 mÅ, and Hg I is absent. However, no reasonable alternative identification of λ3984 is available. It would be most useful to search for the line λ9946, which arises from the same level as λ3984, in stars where both λ3984 and multiplet 1 of Hg I are observed.

h) *Lead*

It is claimed by B^2 that lead is present in the spectrum of α^2 CVn. Since there are no Pb I lines in the red, we consider Pb II. Using the laboratory lists of Earls and Sawyer (1935), the Burbidges claim that two lines of Pb II, λλ4243.1 and 4386.4, both with laboratory intensity 20, are present in α^2 CVn with a mean equivalent width of 22 mÅ each. One of these lines has been identified by S^2 as a Fe I–Cr II blend; the other (4386.4) is unidentified in their list. However, the second line may perhaps be λ4386.57, a predicted line of Fe II, according to Moore (1959).

In the red region there are several strong lines of Pb II. We list them and their identifications below (Table 3).

Since only one of the four lines, each of which should be stronger than the lines in the blue, is present, we conclude that there is no evidence for the presence of Pb II in the spectrum of α^2 CVn.

V. IONIZATION EQUILIBRIUM IN α^2 CVn

Bidelman (1967) has suggested a reconsideration of the possibility of explaining the spectral variations in α^2 CVn by simultaneously varying the temperature and the electron pressure. Swings (1944) and Struve and Swings (1942) criticized this hypothesis, originally presented by Tai (1939), on the ground that Eu II and Eu III vary together.

We have calculated the ionization equilibrium in the temperature range 12000–14500° K, with various electron pressures. We have assumed that $u_i/u_{i+1} = 1$ for all the states involved, and have used an ionization potential of 22 eV for Eu III, as suggested by Sugar (1963). For temperatures greater than 12000° and log P_e less than 2.1 (an unusually low value for a main-sequence A0 star), it is possible to have Eu IV the dominant ion of europium. Then Eu II and Eu III can vary together as the temperature and electron pressure are changed.

TABLE 3

STRONG LINES OF Pb II

λ_{lab}	Lab. Int.	λ_{star}	Ident.	W_λ of Observed Feature
5042 5	50	5042 5A	.	15 mÅ
6075 8	40	absent	. . . . .	<10 mÅ
6081 5	40	6081 6B	6081 5 Cr II	20 mÅ
6660 0	50	absent		<15 mÅ

We seek a solution such that at the maximum number density of Eu II the star is coolest, and at Cr II maximum, when the star is hotter, the Eu II and Eu III number densities are lower. The number densities of the ions of interest are normalized so that the total abundance of the element is unity, and the total variation in temperature cannot be more than 1000° K according to data of Provin (1953) on the color changes throughout the period. We have assumed that the mean excitation potential of Cr II lines is 3 eV, whereas that of Eu II and Eu III lines is 0 eV. This is not unreasonable, since multiplet 1 of Cr II has an excitation potential of 2.4 eV.

It is possible to find a case which marginally resembles this. The best solution, which has rare-earth maximum at $T = 14000°$ K and log $P_e = 1.6$, and rare-earth minimum at $T = 14500°$ K and log $P_e = 1.8$, has the correct phase relationships for the ions Cr II, Eu II, Eu III, and Cl II, with no change in the number density of Sr II over the period. However, even in this case the ratios of number density at maximum and minimum strength are far short of the observed ratios of equivalent widths in α^2 CVn. We are forced to conclude that only a small part of the observed spectral variations can be explained by change in temperature and pressure.

VI. DISCUSSION OF RADIAL VELOCITIES

As can be seen from Table 1, our observational material is poorly distributed in phase. The region from phase 0.0 to 0.65 is adequately covered, but from phase 0.65

to 1.0 there is only one plate. Hence, we have not tried to derive an improved velocity ephemeris; but we have verified that the velocity variations in the red are consistent with those previously obtained in the blue region of the spectrum.

The respective mean velocities were found as a function of phase from the following ephemerides:

$$W_\lambda/\langle W\rangle = 1 + d_{-1}\cos\phi + \delta_{-1}\sin\phi + d_{-2}\cos 2\phi + \delta_{-2}\sin 2\phi\,,$$
$$(W_\lambda/\langle W\rangle)(V - V_0) = V_e \sin\chi(e_{-1}\cos\phi + \epsilon_{-1}\sin\phi + e_{-2}\cos 2\phi + \epsilon_{-2}\sin 2\phi)\,. \quad (1)$$

The coefficients for the velocity groups, given in Table 4, satisfy the constraints imposed by a rigid rotator model, as discussed in Deutsch (1958). They approximately represent the radial velocities of Babcock and Burd (1952), and the equivalent widths of B[2].

The spectrum of the rare earths past 5000 Å is devoid of the extremely strong lines which are found in the blue and ultraviolet. Hence, most of the rare-earth lines disappear at phases near 0.5. Furthermore, many of the rare-earth lines are blends, and it

TABLE 4

FOURIER COEFFICIENTS FOR RADIAL-VELOCITY EPHEMERIDES OF α^2 CVn

Group	A (Rare Earths)	B (Cr)	f (Fe)
d_{-1}	+0.33	−0 16	−0.16
δ_{-1}	−0.03	−0.12	−0.03
d_{-2}	+0 05	−0.20	−0 05
δ_{-2}	−0.01	+0.05	+0.03
$(V_e \sin\chi)e_{-1}$	+2 15	−3.71	−1 51
$(V_e \sin\chi)\epsilon_{-1}$	+8.58	−0.64	+0 75
$(V_e \sin\chi)e_{-2}$	+0.20	−1.00	−0 60
$(V_e \sin\chi)\epsilon_{-2}$	+1.00	−4.00	−1.00

is difficult to determine the dominant contributor. Since there was an insufficient number of lines to establish separate curves for each ion, we have determined mean radial-velocity curves for the singly and doubly ionized rare earths. The curve for the singly ionized rare-earth lines is an average over the total number of observed lines of the radial velocities deduced from the Eu II and Ce II lines, plus 2 times the radial velocities deduced from the Gd II and Sm II lines. The factor of 2 is inserted because according to the curves of S[2], the amplitude of the variations is smaller for the Gd II and Sm II lines than for the Ce II and Eu II lines. Figure 1 shows that the radial-velocity curve thus obtained for the singly ionized rare earths is quite consistent with measurements of previous investigators, where the solid line represents the ephemeris of Table 4 for group A. Note also that the open circles which denote the average of Pr III and Gd III lines (biased toward Gd III, since there are more observed lines of this ion) fit quite closely to the mean curve. Thus the extremely important fact emerges that the singly and doubly ionized rare earths vary together in radial velocity as well as in equivalent width.

The ion Yb II is the only other rare-earth ion with a sufficient number of lines to determine a moderately reliable curve. It appears to fit that of Figure 1 well, except that the amplitude of the variations may be slightly smaller.

The variations in radial velocity deduced in the red for Cr II and Si II are shown in Figures 2 and 3. For Si II the amplitude is quite small and no consistent pattern is seen. The Cr II curve is based on a smaller number of lines, since most of the Cr II lines occur

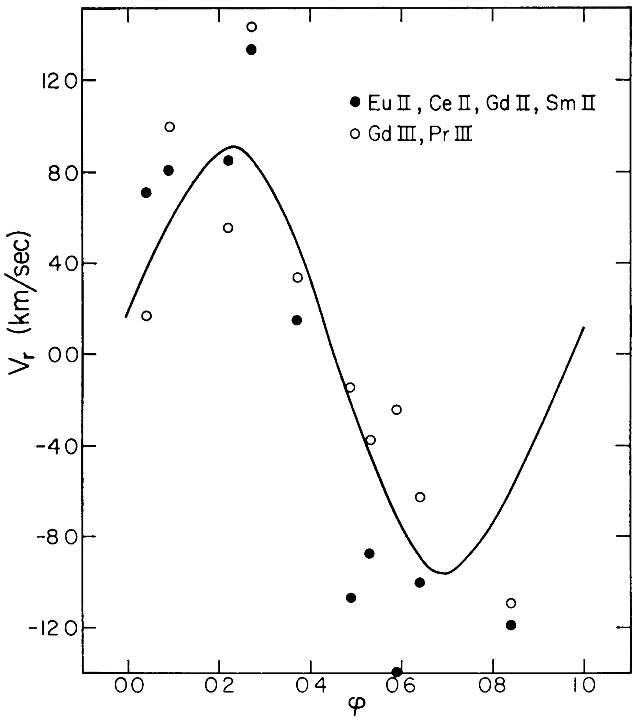

FIG. 1.—Mean radial velocity as a function of phase for rare-earth lines. Filled circles denote V_r for singly ionized rare-earth lines, while open circles represent doubly ionized rare-earth lines. The solid curve is obtained from the ephemeris of Table 4.

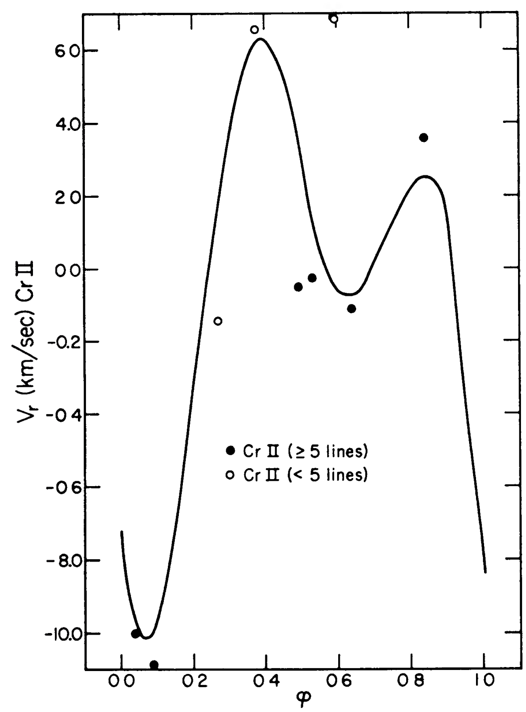

FIG. 2

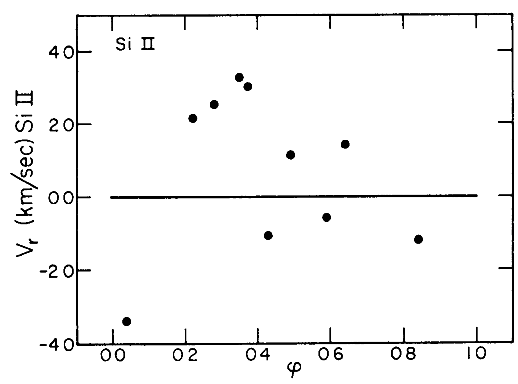

FIG 3

FIG. 2.—Mean radial velocity as a function of phase for Cr II lines. The solid curve is obtained from the ephemeris of Table 4. The open circles are less accurate than the filled circles.

FIG. 3.—Mean radial velocity as a function of phase for Si II lines.

at wavelengths less than 5600 Å, and many of them are blended. However, allowing for some scatter, it agrees well with the curve given by the ephemeris of Table 4 for group B, indicated by the solid line.

In determining the radial-velocity curve of Fe II, we have used only those lines which are listed as Fe II in Moore (1959), so that accurate wavelengths are available. The results, shown in Figure 4, are based on many lines, but are not consistent with the solid line, which is based on the ephemeris of Table 4 for Fe II. Rather, they are much closer to the radial-velocity curve obtained by Pyper (1968), indicated by dotted lines. We do not have sufficient resolution to see any doubling of the lines; however, at some phases the Fe II lines appear unusually broad on the tracings. A detailed discussion of the cause of the different Fe II velocity curves and their theoretical significance will be published by Miss Pyper.

The assignment of ions to groups A, B, and C as defined in § I based on the present material is given in Table 5. It seems clear that group B must be further subdivided, and that the variations in radial velocity of its members probably are not similar to each other.

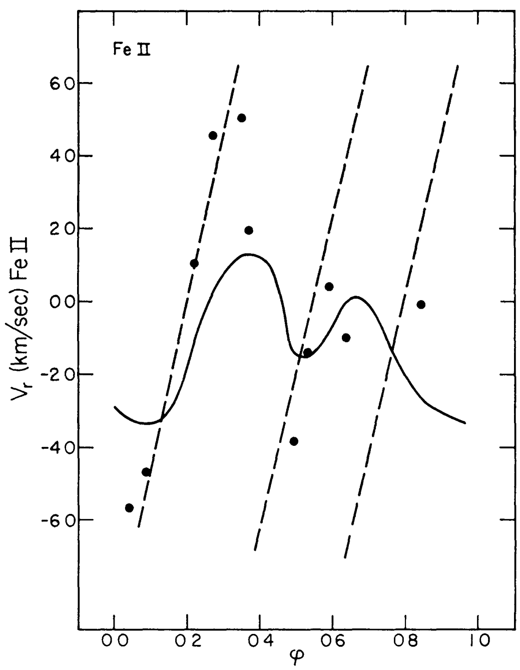

FIG. 4.—Mean radial velocity as a function of phase for Fe II lines. The solid curve is obtained from the ephemeris of Table 4, while the dotted curve is that of Pyper (1968).

TABLE 5

GROUP ASSIGNMENTS OF IONS IN α^2 CVn

A		B	C
Cl II	Pr II	Cr II	Si II:
Ti II	Pr III:	Fe I:	
Mn II	Sm II	Fe II	
Y II:	Eu II		
La II:	Gd II		
Ce II	Gd III		
	Yb II		

VII. CONCLUSIONS

The unusual spectroscopic properties revealed by α^2 CVn are not easily explained by the hypothesis of surface or interior nuclear reactions. The presence of Cl II and absence of P II, as well as the absence of Pb II, cast doubt on the possibility of creating a reaction network which could produce the observed peculiarities. In addition, the cause of the spectral variations is poorly understood. Further theoretical work on physical processes in stars with large magnetic fields which might produce patches of abnormal composition is required.

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